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The market for catastrophe risk: a clinical examination☆

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Abstract

This paper examines the market for catastrophe event risk – i.e., financial claims that are linked to losses associated with natural hazards, such as hurricanes and earthquakes. Risk management theory suggests protection by insurers and other corporations against the largest cat events is most valuable. However, most insurers purchase relatively little cat reinsurance against large events, and premiums are high relative to expected losses. To understand why the theory fails, we examine transactions that look to capital markets, rather than traditional reinsurance markets, for risk-bearing capacity. We develop eight theoretical explanations and find the most compelling to be supply restrictions associated with capital market imperfections and market power exerted by traditional reinsurers. © 2001 Elsevier Science S.A. All rights reserved.

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1. Introduction

Hurricanes, earthquakes, wind and ice storms, floods, etc. have long been known to cause large and unexpected losses to owners of physical capital. Recently, it has become widely appreciated that a single hurricane or earthquake could result in damages of $50–$100 billion. Given the growth rates in physical asset values and in population in high-risk zones, distribution of catastrophe event losses continues to grow.[1]

Because households are risk averse, they have a strong incentive to share their risks with others through the purchase of insurance. Corporations, depending on their level of concern with risk management, also have an incentive to purchase insurance. Insurers are particularly motivated purchasers of reinsurance since they would otherwise become concentrated warehouses of catastrophic exposures. If corporations in general and insurers in particular behave in a risk averse manner with respect to these exposures, then they treat severe losses as expectationally more costly than moderate losses. One would therefore expect that reinsurance is focused on catastrophic outcomes. Moreover, since cat event losses are uncorrelated with (and perhaps even independent of) financial wealth, the premiums for such catastrophic protection should, if markets are perfect, approximate expected losses.

This paper explores these propositions, provides both large-sample and clinical reinsurance data on their veracity, and then attempts to understand why they fail. We first use evidence from a large and unique dataset of reinsurance transactions to show that protection in general is far more limited and prices are far higher than can be readily explained by the theory. We then try to understand these deviations better using clinical information. We look at several recent, widely-discussed transactions by USAA (one of the largest insurance companies in the US) and the California Earthquake Authority (a state insurance pool set up to help fund earthquake losses). They are among the first to back reinsurance with dedicated collateral supplied by bondholders. Traditionally, reinsurance contracts have been backed by the general credit of reinsurers, who use equity in ongoing reinsurance businesses to fund themselves. These newer bond transactions display the features mentioned above, i.e., high prices and limited quantities. But the process of innovation that they represent is in itself interesting, reveling clues about the imperfections and inefficiencies of the reinsurance marketplace that economists' models tend to miss.

The paper then turns to develop alternative hypotheses, eight in total. The majority of these focus on distortions on the supply side, but several suggest problems with the demand side as well. The most important explanations

[1] For related work on the market for catastrophe risk, see Cummins, Doherty, and Lo (2000) and Jaffee and Russell (1997).

concern supply-side phenomena of capital market imperfections facing reinsurers and the exercise of market power by reinsurers.

In many respects, the evidence is most interesting for its implications beyond that of the cat risk market itself. In the conclusions, we discuss several lessons drawn from this evidence for the broader behavior of capital markets and corporate risk management.

2. The optimal reinsurance profile

We begin with a brief overview of theory. In the classical world without imperfections, fairly priced reinsurance, like any other corporate risk management transaction, is a zero-NPV transaction, and therefore cannot affect corporate value. So if we are to consider the optimal reinsurance profile, it needs to be in a context in which risk management matters. The framework we use here is that of Froot et al. (1993). [See also Froot and O'Connell (1997), who develop a related model of the supply of and demand for reinsurance]. The basic approach is that value-maximizing corporations face financing imperfections that make external capital more expensive than internal capital. Corporate hedging can raise value by conserving on external financing and replacing it with cheaper, state-by-state internal funds for use in profitable investment opportunities.

Several important papers derive results similar to those below. In particular the classic work by Borch (1962) and Arrow (1965) shows that optimal insurance contracts for risk averse individuals contain deductibles.[2] Several papers demonstrate how, in the corporate context, insurance contracts help solve underinvestment and agency problems – see, for example, Mayers and Smith (1982, 1987) and Garven and MacMinn (1993). An important distinction added by the corporate perspective in these papers as well as in Froot et al. (1993) and the present paper is that the fair expected return received for bearing a financial risk does not influence the corporate hedging decision, but does affect the hedging or allocation decision of a risk averse individual.

Following Froot et al. (1993), consider a value-maximizing firm facing financing imperfections that add to the cost of raising external funds. The future-period value of the firm is given by $P = P(w)$, where w measures internal capital. In the first period, w is a random variable that depends on the future realization of cat events, ε.

The model has two time periods, present and future. In the present period, the insurer makes a reinsurance (i.e., hedging) decision regarding its catastrophic

[2] Mayers and Smith (1983) and Doherty and Schlesinger (1983), consider optimal insurance contracts as part of a financial portfolio.

exposures by maximizing the expected value of the firm, E[$P(w)$]. In the future period, the insurer realizes a cat event shock and maximizes shareholder value subject to financing imperfections. These imperfections alter the shape of the value function $P(w)$, which without them would be linear. Following Froot et al. (1993), P satisfies $P_{ww} < 0, P_w \geqslant 1$. Future period internal funds are $w = w_0 \varepsilon$, where w_0 is the initial level of internal capital, and ε is the random loss from a cat event, with ε distributed with mean zero and with a distribution function, $f(\varepsilon)$, whose hazard rate, $f(\varepsilon)/(1 - F(\varepsilon))$, is strictly increasing over the support $\varepsilon \in (-\infty, 1]$. To keep things simple, we choose units such that $w_0 = 1$. Thus, if there is no cat event, internal funds remain at unity.[3]

In the first period, the insurer can purchase a reinsurance contract against some range of event losses. We define reinsurance contracts in a way that parallels those actually observed. Specifically, we use "excess-of-loss layers," which are bands of protection associated with cat-triggered loss amounts. The main parameters of an excess-of-loss layer are the "retention," "limit," and "exceedence"/"exhaustion" probabilities. The retention is simply the deductible, i.e., the level that losses must exceed before coverage is triggered. The probability that losses reach this level is the exceedence probability. The contract limit is the maximum recovery that can be made under the contract. The probability of reaching a loss that exhausts the limit is the exhaustion probability. Essentially, reinsurance layers are call spreads written on a company's underlying cat losses: long one call struck at the retention or exceedence point, short one call struck at the retention plus limit, or exhaustion point. The risk period for these contracts is typically one year.

In the context of the model, we let the insurer choose a retention, r, and a limit, l, which together define an excess-of-loss layer of insured ε shocks, $[r - l, r] \subset (-\infty, 1]$. For simplicity, we assume the insurer buys complete reinsurance on this interval and that the reinsurance is fairly priced. We also subject the insurer to a spending constraint, B, for premiums spent on the layer.

Under these assumptions, next-period wealth is given by the shock, ε, less expected losses (i.e., fair premiums), plus reinsurance claims:

$$w(\varepsilon) = \varepsilon - \left[\int_{r-l}^{r} (r - \varepsilon)\, \mathrm{d}F(\varepsilon) + \int_{-\infty}^{r-l} l\, \mathrm{d}F(\varepsilon) \right] + [(r - \varepsilon)(r - l < \varepsilon < r) + l(\varepsilon < r - l)], \tag{1}$$

where $r - \varepsilon$ is the payment under the reinsurance contract when ε falls in the region $[r - l, r]$, and l is the payment when ε is in the range $[-\infty, r - l]$.

[3] Froot et al. (1993) prove that $P_{ww} < 0, P_w \geqslant 1$ follow from a costly-state verification model of external financing, provided that the hazard rate $f(\varepsilon)/(1 - F(\varepsilon))$ is strictly increasing.

In the first period, the insurer chooses the reinsurance it wishes to buy by maximizing future value subject to the premium constraint:

$$\max_{r,l} \quad E_\varepsilon\,[P(w(\varepsilon))]$$

$$\text{s.t.} \quad \left[\int_{r-1}^{r} (r-\varepsilon)\,\mathrm{d}F(\varepsilon) + \int_{-\infty}^{r-1} l\,\mathrm{d}F(\varepsilon)\right] \leqslant B. \tag{2}$$

Without the budget constraint, the unconstrained insurer would set $[r-l, r] = (-\infty, 1]$. In other words, the limit would be infinite and the retention would be set at a loss of zero (with no cat event, we have $\varepsilon = r = 1$). The insurer would therefore be fully hedged against the cat shock. Clearly, the premium constraint is not binding unless B is strictly less than the required premium for the unconstrained contract:

$$B < \left[\int_{-\infty}^{1} (1-\varepsilon)\,\mathrm{d}F(\varepsilon)\right]. \tag{3}$$

The premium constraint, B, is added to allow the firm to be cash constrained in the first period even in the presence of the reinsurance contract. For example, a firm that held B in first-period internal cash would have a premium constraint of B if it had no first-period access to the capital markets. That is formally our assumption here. However, the more general notion is that the firm may experience costs of first-period as well as later-period access to external finance and will therefore need to balance them. In such a case, the firm that faces costs of external finance will in general spend less on reinsurance premiums than the unconstrained firm in the specification above.

The first-order conditions for the problem in (2) with respect to r and l are

$$-\int_{r-l}^{r} \mathrm{d}F(\varepsilon) \int_{-\infty}^{\infty} P_w\,\mathrm{d}F(\varepsilon) + \int_{r-l}^{r} P_w\,\mathrm{d}F(\varepsilon) = \lambda \int_{r-l}^{r} \mathrm{d}F(\varepsilon)$$

and

$$-\int_{-\infty}^{r-l} \mathrm{d}F(\varepsilon) \int_{-\infty}^{\infty} P_w\,\mathrm{d}F(\varepsilon) + \int_{-\infty}^{r-l} P_w\,\mathrm{d}F(\varepsilon) = \lambda \int_{-\infty}^{r-l} \mathrm{d}F(\varepsilon) \tag{4}$$

Combining these gives:

$$\int_{r-l}^{r} P_w\,\mathrm{d}F(\varepsilon) \int_{-\infty}^{r-l} \mathrm{d}F(\varepsilon) = \int_{-\infty}^{r-l} P_w\,\mathrm{d}F(\varepsilon) \int_{r-l}^{r} \mathrm{d}F(\varepsilon). \tag{5}$$

Note that with the firm completely insured over the interval $[r-l, r]$, w becomes a constant over the corresponding range of ε. Thus, $w(r^*) = w(r^* - l^*)$, $\forall \varepsilon \in [r^* - l^*, r^*]$, so $P_w(w(r-l))$ can be taken out of the

integral on the left-hand side. Thus,

$$\int_{-\infty}^{r-l} P_w(w(r-l))\,\mathrm{d}F(\varepsilon) = \int_{-\infty}^{r-l} P_w(w(\varepsilon))\,\mathrm{d}F(\varepsilon). \tag{6}$$

Since P_{ww} is negative, $P_w(w(r-l)) < P_w(w(\varepsilon)), \forall \varepsilon < r-l$. In other words, the need to hedge, as measured by the marginal value of external funds, is greatest for the most severe risks. The only way to satisfy the equality in Eq. (6) is to set l to $-\infty$. The spending constraint, because it is binding, then determines $r \in (-\infty, 1]$.

Thus,

Proposition. *When reinsurance is priced fairly, the optimal reinsurance profile protects against unboundedly large events first; the benefit of hedging higher probability layers is less. The retention is then set at lower loss levels as the spending constraint, B is relaxed. The optimal layer satisfies* $[r^* - l^*, r^*] = (-\infty, z]$, where $z < 1$.

Fig. 1 demonstrates the intuition for this result graphically. The shaded region shows the optimal interval over which ε is fully hedged. Larger risks are hedged first, and the retention, r, moves up continuously as the spending limit is relaxed.

3. The aggregate profile of reinsurance purchases

We next investigate actual catastrophe reinsurance purchases across the insurance industry. We ask two questions. First, is the profile of reinsurance purchases similar to that predicted by the model above? Second, how are prices related to expected losses on reinsurance contracts (in the model above, they are assumed to be equal)?

To determine the reinsurance quantities and prices for a broad group of insurance companies, we apply actual reinsurance transaction data obtained from Guy Carpenter & Company, the reinsurance brokerage subsidiary of Marsh McLennan, Inc. and by far the largest US cat risk intermediary. These data include over 4,000 cat reinsurance layers for 22 nationwide insurers and a large number of regional insurers for the years 1970–1998, all of which were brokered by Guy Carpenter & Company

3.1. The fraction of exposure reinsured

We use these data to calculate the fraction of aggregate insurer exposure that is reinsured for different sized aggregate events. To do this, we must relate the losses on individual contracts to aggregate cat event losses. For each contract,

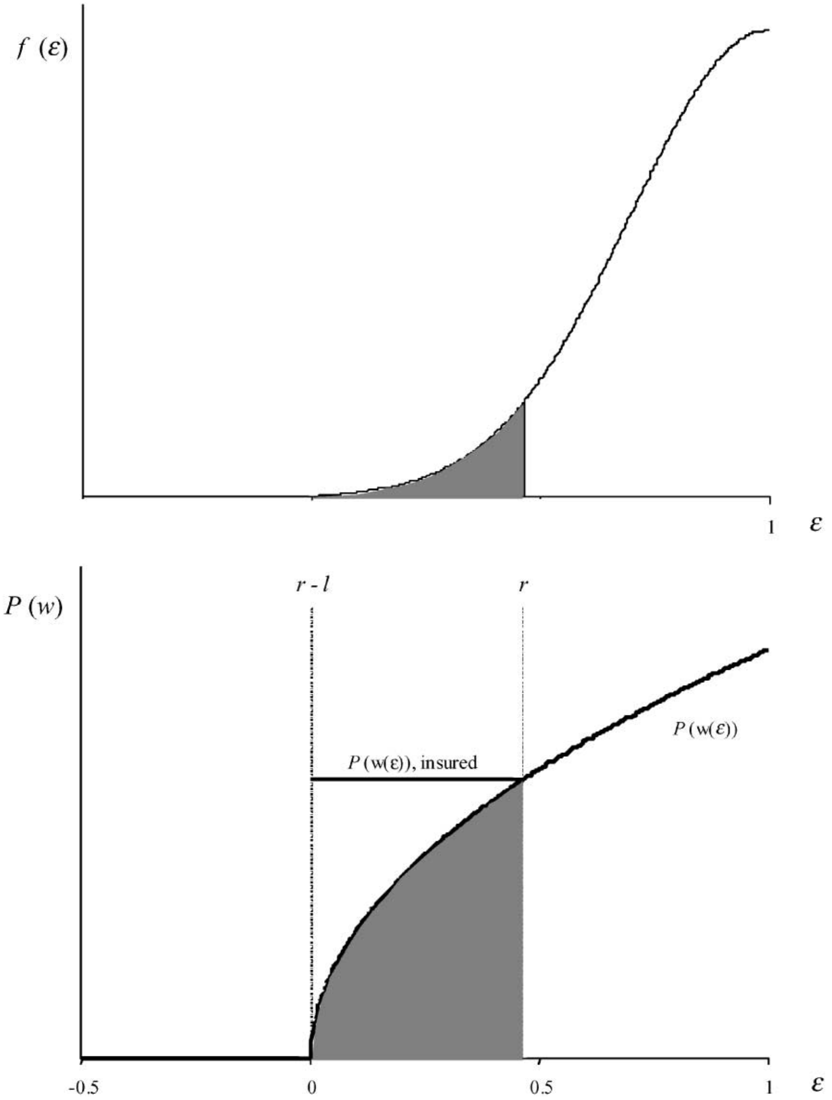

Fig. 1. Optimal constrained hedging program. Shaded region indicates the range of event-loss outcomes, ε in which an insurer would optimally reinsure, if given the choice of range over which it could fully insure against losses at fair value. The top panel shows the frequency distribution of event losses while the bottom panel shows the value of the firm as a function of event losses. The reinsurance contract provides complete protection for outcomes above the amount of the retention less the limit, $r - l$, and below the retention, r.

we link individual firm retention and exhaustion loss amounts to a level of industry-wide losses. This is done using data on US regional market shares for each firm and year from A.M. Best. So, for example, a nationwide firm that has a 10% market share of cat-sensitive premiums is calculated to incur 10% of the aggregate industry losses. For such a firm, a reinsurance layer of \$100 million (limit) in excess of \$150 million (retention) is calculated to provide protection for industry-wide losses of between \$1.5 billion and \$2.5 billion. This procedure is discussed in detail in Froot and O'Connell (1997).

Fig. 2 shows the relation in these data between the fraction of pooled insurer exposure covered by reinsurance and the size of industry-wide events in 1994 dollars. The fraction of coverage is based on marginal (not total) losses. So, for example, 50% coverage for a \$3 billion national event implies that one half of an additional dollar of loss at the \$3 billion level is covered by reinsurance.

There are two main points to be made from Fig. 2. First, the profile of reinsurance purchases does not mirror that predicted by the model above. Reinsurance coverage as a fraction of exposure is high at first (after some small initial retention) and then declines markedly with the size of the event, falling to a level of less than 30% for events of only about \$8 billion. Such events today are not very large; aggregate statistics suggest that an \$8 billion event occurs

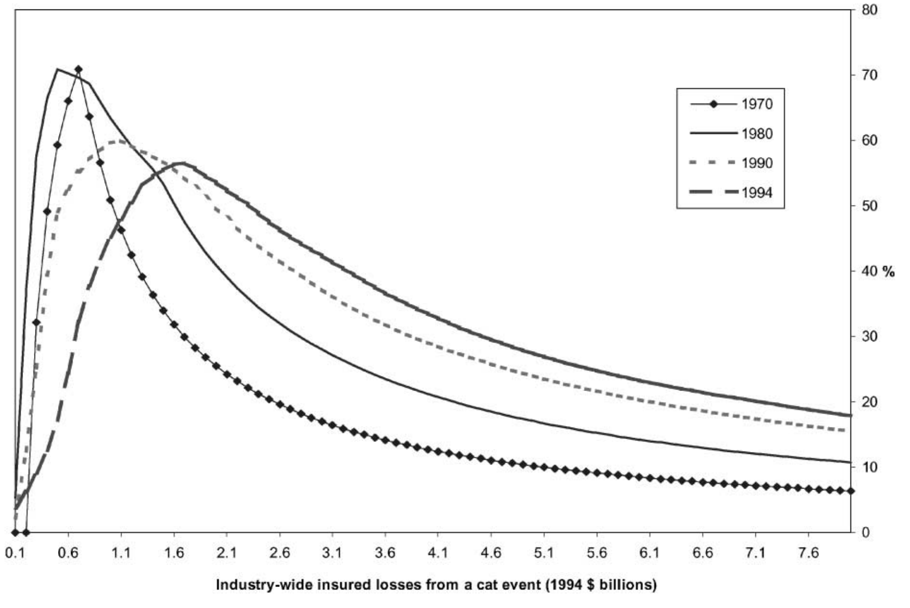

Fig. 2. Percentage of exposure that insurance companies reinsure (by various event sizes). This graph shows the amount of a marginal dollar of industry-wide loss that is reinsured against catastrophic losses in a sample of insurance companies that purchase reinsurance through Guy Carpenter & Company.

annually with probability of about 9%. So only a small fraction of large event exposures have historically been covered, and if anything, Fig. 2 overstates that fraction. That is because only insurers who actually purchased reinsurance are included in the data; those that do not purchase reinsurance are excluded from the denominator. The implication is that insurance companies tend to retain, rather than share, their large-event risks. Furthermore, insurers themselves intermediate only a small fraction of cat exposures. Many exposures faced by the corporate and household sectors are not intermediated at all. Corporations, for example, tend to self-insure, and particularly so against large losses, even while purchasing insurance against small losses. Doherty and Smith (1993) document that insurance coverage is limited for corporate cat losses of between $10 million and $500 million (for a single corporation) and virtually nonexistent for losses above $500 million. This suggests that the hedging profile of the insurance industry is similar to that of corporate insurance purchases. The vast majority of primitive cat risk in the economy is being retained. This suggests a lack of complete risk sharing, and the failure of the insurance and reinsurance sector to help accomplish it, is on a scale greater than that shown in Fig. 2.

Second, Fig. 2 provides a comparison of the reinsurance profiles at different points in time, suggesting that retentions increase after a large event. For example, between 1990 and 1994, Hurricane Andrew (Florida) and the Northridge earthquake (California) resulted in roughly $20 billion and $13 billion, respectively, in industry-wide damages. Fig. 2 shows that, during this time period, the fraction of exposures reinsured for medium events (between $2 billion and $8 billion) increases, while the fraction of exposures reinsured for small events (under $2 billion) actually falls. This is unlike the changes that occurred in previous periods. One explanation is that reinsurance contract retentions shifted upward. In other words, when coverage for large events increases after an event, it appears to do so at least partly at the expense of small-event coverage. Further evidence on this point is given below.

3.2. *The price of reinsurance*

Next we turn to the prices paid for reinsurance. We employ the same dataset to examine average premiums on reinsurance contracts relative to expected loss. Before doing so, however, we briefly discuss the use of expected loss as a benchmark for fair value.

3.2.1. *Expected losses as fair-value premiums*

Our use of expected losses as the fair-value benchmark hinges on two assumptions. First, it assumes that cat risk is diversifiable in equilibrium. A sufficient condition is that cat risk returns are independent of total wealth. Not surprisingly, the data provide no evidence to reject this assumption. It should be noted, however, that existing tests examine only correlations (i.e.,

second and not higher moments) with other financial assets, finding them to be zero. In addition, cat events have a clear and direct effect on nonfinancial assets (e.g., housing), so correlations with financial assets can be misleading.[4]

The second assumption we make in using expected loss as a benchmark is that the expected loss numbers produced by models of contract exposures are unbiased. While there is uncertainty about the true probabilities, the presence of uncertainty, per se, should not matter under expected utility theory. Agents should care only about gamble outcomes provided they have unbiased estimates of outcome probabilities.[5] However, given the paucity of rich cat event data, there may be a common bias in the estimated event probabilities made by the cat models. But even if such a bias exists, it is hard to understand why the capital market would think it knows more about unbiased cat-event loss probabilities than do specialized cat modeling firms. As long as the capital markets take model-expected losses to be unbiased based on currently available information, our unbiasedness assumption is satisfied.[6]

3.2.2. The aggregate pricing of cat reinsurance

The next question is the pricing of cat risk in the broad reinsurance marketplace. To address this, we again apply reinsurance contract data from Guy Carpenter & Company. As in the section above, we first link these individual contracts to industry-wide losses. That is, we use market share information to distribute the total industry losses of a cat event across industry participants, so, for example, a company with a 10% market share is assumed to bear 10% of total industry losses. To calculate fair-value pricing, we also need to calculate industry-wide cat event loss distributions. That is, we need to determine that an industry-wide event of $\$x$ billion occurs with probability y. To do this, we estimate distributions for both the frequency (how often do events occur) and the severity (how large are the associated damages). We do this across different perils (e.g., earthquake, hurricane, winter storm, etc.), five different US regions, and four seasonal quarters. This gives us distributions for, as an example, frequency and severity of Northeast-region earthquakes during the spring. Using this distributional information together with each firm's market shares across each of the five US regions, we are able to derive a probability

[4] See Froot et al. (1995) and Litzenberger et al., (1996). It is worth noting that, because of low power, there is little to be gained from investigating higher-order moments. Yet, because cat risk is highly non-normal even in continuous time, cat risk can easily alter the higher-order moments of wealth. Fortunately, for risk exposures that are small in comparison with the risk of total wealth, the effects of higher-order moments are small.

[5] See Bantwal and Kunreuther (2000) for a discussion of departures from expected utility and its implications for cat pricing.

[6] On the impact on pricing of uncertainty of event probabilities, see Froot and Posner (2000).

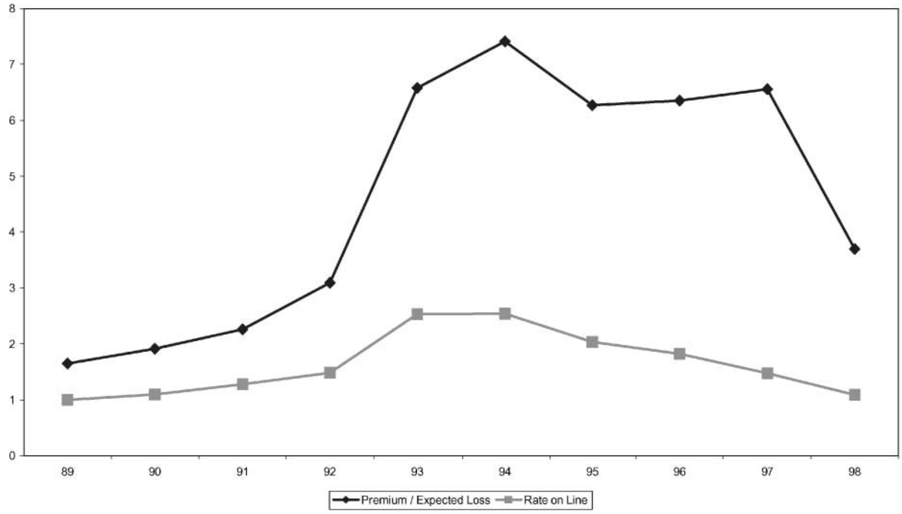

Fig. 3. Premium/expected loss and rate on line (premium/limit) for reinsurance contracts, 1989–1998.

distribution of losses for each individual reinsurance contract. We then estimate expected losses by Monte Carlo simulation.[7]

Fig. 3 depicts the ratio of premium to estimated expected loss across reinsurance contracts. For comparison, we also graph an index of premiums relative to limit, a ratio that, in reinsurance parlance, is known as "rate on line." Here rate on line is calculated as the average across contracts of the ratio of premium to limit, and (for comparison purposes only) is set equal to the premium-to-expected-loss curve in 1989. Note that the index of rate on line contains no calculation of expected loss, so it is immune to any measurement errors in our estimates of expected loss. Of course, rate on line is also unable to provide information about shifts in retentions.

Fig. 4 breaks down each treaty by layer, in order to measure premium to expected loss by exceedence probability. Higher deciles represent lower exceedence probabilities.

Several points emerge from Figs. 3 and 4. First and foremost, industry-wide prices – premium/expected loss – are considerably greater than one, our benchmark for fair value. Fig. 3 shows that premiums are more than seven times expected loss during the period, and at no time are less than expected loss. Fig. 4 offers an additional breakdown of this trend. It shows that much of the high premium-to-expected-loss ratio in Fig. 3 comes from the lower-probability

[7] See Froot and O'Connell (1997) for a detailed discussion of the methodology.

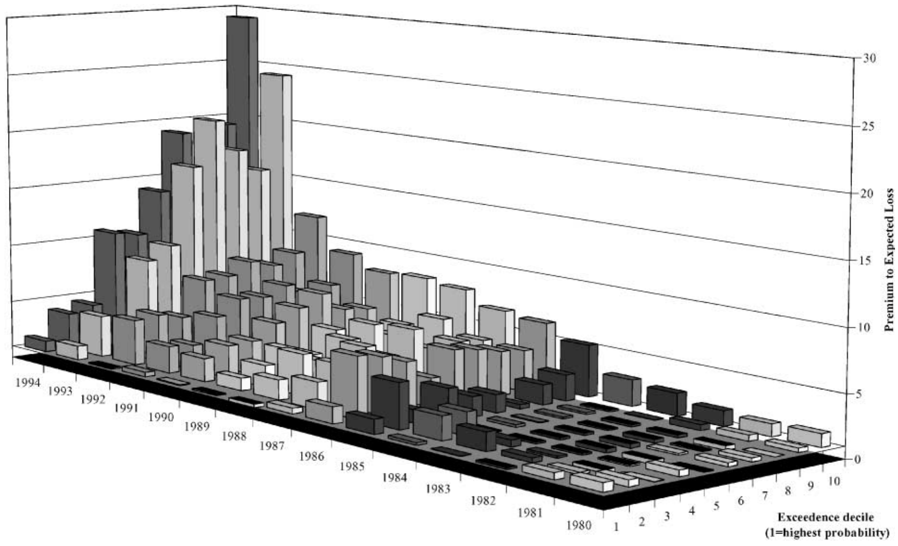

Fig. 4. Premium / expected loss, by exceedence probability and year.

layers. Average prices, and particularly those on lower-probability layers, are considerably above fair value.

Second, the time-series variation in prices is interesting. Reinsurance became considerably more expensive during the 1990s, with premiums rising by three times expected losses between 1992 and 1993 alone (contract terms for each year are set in January). This large price increase follows immediately the occurrence of Hurricane Andrew in August 1992. There were so few large storms between 1970 and 1992 (and none near the size of Andrew), that it is difficult to find a historical analogue to gauge this price shift. Since the 1994 Northridge earthquake, only relatively minor insured cat losses have occurred.

Third, note that prices have declined in 1998 by a factor of two from the post-Andrew-Northridge levels. The decline has occurred smoothly since 1994 when measured in terms of rate on line. However, premium-to-expected-loss fell strongly only in 1998. The reason for this disparity is that the premium-to-expected-loss curve picks up changes in retention levels. As mentioned above, retention levels rose in the post-Andrew period, 1992 to 1994. From 1994 to 1997, it appears that retentions continued to rise, insofar as the rate on line curve declines while the premium-to-expected-loss curve does not. Only in 1998 do retentions begin to fall.

Fourth, Fig. 3 suggests a cyclical price path triggered by large events. It is argued that similar price cycles are observed in other insurance markets.[8] So

[8] For evidence of price cycles in insurance, see for example, Gron (1994).

even though there are not many comparable cat events in the US record, there is a strong presumption in the catastrophe marketplace that these price fluctuations are part of a kind of event-driven price cycle.

Fifth, given the paucity of event data, one should naturally be skeptical of estimates of expected loss. After all, there is by definition little empirical information on rare catastrophic events. Even though our estimates agree broadly with those of the disaster-modeling firms, it is possible that there is a systematic underestimation of true expected losses across methodologies.[9] If true, this would lead us to overstate the cost of cat reinsurance.

However, one might argue that even if the level of our estimates is in error, it is unlikely that the price changes in Fig. 3 are prone to large errors. It seems hard to argue that rationally-estimated expected losses increased and then decreased so substantially over such a short period of time. If an event occurred that was thought to be of low probability, a good Bayesian with little prior information might indeed update substantially the probability of reoccurrence. However, nonoccurrence of such an event would give such a Bayesian little new information since the event was unlikely to occur in the first place. Thus, it is hard to understand how any rational scheme for estimating probabilities would yield a quick and precipitous decline as a result of a nonevent.

3.3. Summary

It is clear from this evidence that the Froot et al. (1993) model cannot explain reinsurance purchasing behavior. Reinsurance purchases should prioritize the highest layers, which are associated with the most severe events. Instead it seems that reinsurance is more prevalent for mid- and small-size events, after adjusting for deductibles.

It also appears that fair pricing does not prevail in the markets for these reinsurance claims, and that premiums are a multiple of expected loss. It is conceivable that a downward bias in our measures of expected loss could explain this result. However, that downward bias cannot explain the "cycle" in prices that appears subsequent to a large cat event, wherein prices first strongly rise and then fall over time.

It would seem that the predictions of the Froot et al. (1993) model with fair pricing can be rejected on the basis of these facts. What is less clear is whether we are approaching the problem correctly. What alternative stories would explain the patterns of reinsurance prices and purchases? Are adverse selection, informational asymmetries, or agency problems important aspects of what is going on?

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[9] Cat modeling firms use complex Monte Carlo simulations with many sources of uncertainty and many parameterized distributions. Nevertheless they also can work only with historical data which is highly limited. For investigations of the uncertainty in cat event model estimates, see Bantwal and Kunreuther (1999), Major (1999) and Moore (1998).

If so, what are the empirical consequences of these imperfections? To help answer these questions, and to put additional perspective on the issues, we next explore clinically several cat reinsurance transactions.

4. Reinsurance contracts: clinical evidence

In this section we focus primarily on USAA's recent reinsurance purchases, although we also investigate a related transaction by the California Earthquake Authority.

4.1. USAA: the company

USAA is the fifth largest private passenger automobile insurer and the fourth largest homeowner insurer in the United States. It sells exclusively to US military officers and their families and is organized as a mutual insurance company. Because of its military customer base, USAA has relatively little control over the geographic pattern of its exposures that come disproportionately from California and Florida.

The risk of hurricane in the southeastern US is a real one for USAA. In August 1992, Hurricane Andrew swept through Florida and Louisiana, causing losses of \$620 million to USAA and approximately \$17.9 billion to the insurance industry overall, of which 67% was residential.[10,11] Small changes in Andrew's trajectory would have resulted in major changes in total industry and USAA losses.

4.2. USAA's 1997 reinsurance program

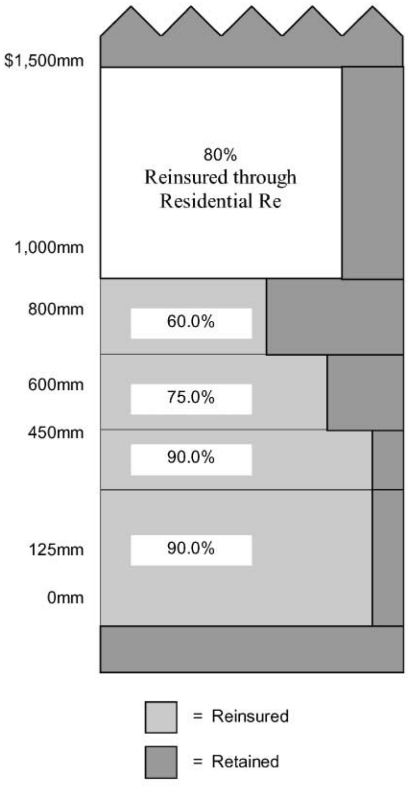
In many respects, USAA's catastrophe reinsurance program looked like the programs of other insurers. USAA had historically purchased reinsurance in excess-of-loss layers conforming to different cat-triggered loss amounts.[12] USAA also tended to "coinsure" a portion of the layer (coinsurance was a typical device requiring the cedent to pay between 5% and 20% of the loss in any given layer). The risk period for USAA's contracts was one year, as was typical.

Fig. 5 and Table 1 provide a simple depiction of the layers of USAA's 1997 reinsurance program. In prior years, USAA had purchased reinsurance to cover

[10] See Major (1997).

[11] Dollar amounts in the text are in 1996 dollars unless stated otherwise.

[12] Only paid claims associated with event-triggered losses are reimbursable under standard cat reinsurance contracts.



Layer #	Annual Premium	Illustrative ROL	Comments
5	$24.0mm*	6.0%*	Securitized by Residential Re
4	$6.6mm	5.5%	Excludes California and Autos
3	$15.0mm	10.0%	Excludes Autos
2	$16.9mm	12.5%	Excludes Autos
1	$24.4mm	7.5%	FHCF Hurricanes in FL Only

Calculation of ROL for Layer 2

Premium Paid:	$16.9mm
Limit:	90%*(600-450) = 90%*(150) = $135.0mm
ROL:	Premium / Limit = $16.9mm / $135.0mm = 12.5%

Calculation of premium to expected loss for Layer 2

ROL of Layer 2:	12.5%
Actuarial Prob. of Loss > $450mm:	4.5%

$$\text{Price: } = \frac{12.5\%}{4.5\%} = 2.8$$

Fig. 5. USAA's 1997 Reinsurance Program (contracts in force from July 1997 to June 1998). With the exception of the top layer reinsured by Residential Re, the premiums and illustrative ROLs shown in this exhibit are not the prices and rates paid by USAA. Due to the sensitive nature of the information, only illustrative rates have been provided. * Rumors in the market were that Layer 5 would cost approximately 5% ROL for traditional reinsurance (private communication with Guy Carpenter, Inc. brokers.).

Table 1
Residential Reinsurance, Cat Bond Contract specifications

Obligor:	Residential Reinsurance Limited, a Cayman Island reinsurance company, whose sole purpose is to provide reinsurance for USAA		
Amount:	Class A-1:	\$164 mm	\$87 mm principal variable \$77 mm principal protected
	Class A-2:	\$313 mm	100% principal variable
Yield:	LIBOR + 576 basis points		
Loss occurrence:	One Category 3, 4, or 5 hurricane		
Reinsurance agreement:	Residential Reinsurance Limited will enter into a reinsurance agreement with USAA to cover approximately 80% of the \$500 mm layer of risk in the excess of the first \$1,000 mm of USAA's ultimate net loss		
Ultimate net loss:	Ultimate net loss = amount calculated in Step 6 (below)		
	Step 1	All losses under existing policies and renewals	
	Step 2	All losses under new policies	
	Step 3	9% of the amount calculated in Step 1	
	Step 4	Add the amount from Step 1 with the lesser of Steps 2 and 3	
	Step 5	Multiply Step 4 by 1.02 for boat and marine policies	
	Step 6	Multiply Step 5 by 1.02 to represent loss adjustments	
Coverage type:	Single occurrence		
Coverage period:	June 16, 1997 to June 14, 1998 (see Fig. 6b)		
Ratings:	Class A-1:	Rated AAAr/Aaa/AAA/AAA by S&P, Moody's, Fitch, and D&P, respectively	
	Class A-2:	Principal variable notes are rated BB/Ba/BB/BB by S&P, Moody's, Fitch, and D&P, respectively	
Covered states:	Alabama, Connecticut, Delaware, District of Columbia, Florida, Georgia, Louisiana, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Texas, Vermont, and Virginia		

losses up to \$1 billion. Yet the company had not been comfortable with stopping at \$1 billion. The associated exceedence probability of approximately 1% was higher than USAA believed was prudent from the perspective of its policyholders. USAA was a conservatively run company, and represented itself as such.

As a result of these considerations, USAA decided to extend its coverage up to losses of \$1.5 billion. It had not taken this alternative seriously for earlier programs because layers with such high retentions were generally extremely expensive (see Fig. 4) or simply unavailable, due to capacity constraints. In the planning period leading up to 1997, USAA could not have relied on being able to purchase this coverage in the reinsurance market.

The lack of reasonably-priced capacity for this higher layer had compelled USAA to begin exploring sources of risk-bearing capacity other than traditional reinsurers. According to Steve Goldberg, the chief architect of USAA's capital market's effort, the reasoning was that "traditional reinsurance capacity is

necessarily limited ... " and that what was needed for USAA as well as other intermediaries was a long term "supplement of additional capacity".[13]

Developing alternative sources of capacity was not simple, quick, or cheap. USAA began contemplating reinsurance from non-traditional sources beginning in 1993. By mid-1995, proposals had been requested from bankers on securitized risk transfer ideas. By early 1996 USAA had selected three investment banks for the execution of a cat bond transaction for the hurricane season beginning in July 1996. However, even though the bankers had four or five months to construct the transaction, it could not be completed that year. Among the most important reasons were that: few investors understood the securities (described below); rating agencies had no established criteria on which to rate such securities; regulators had to agree that noteholders were not, in fact, writing insurance (something that noteholders generally were not licensed to do); and legal, regulatory and tax complications made finding the right location for the special purpose reinsurance entity complicated. Because of these problems, the issue did not come to market until mid-1997 for the risk period running from June 1997 to June 1998.

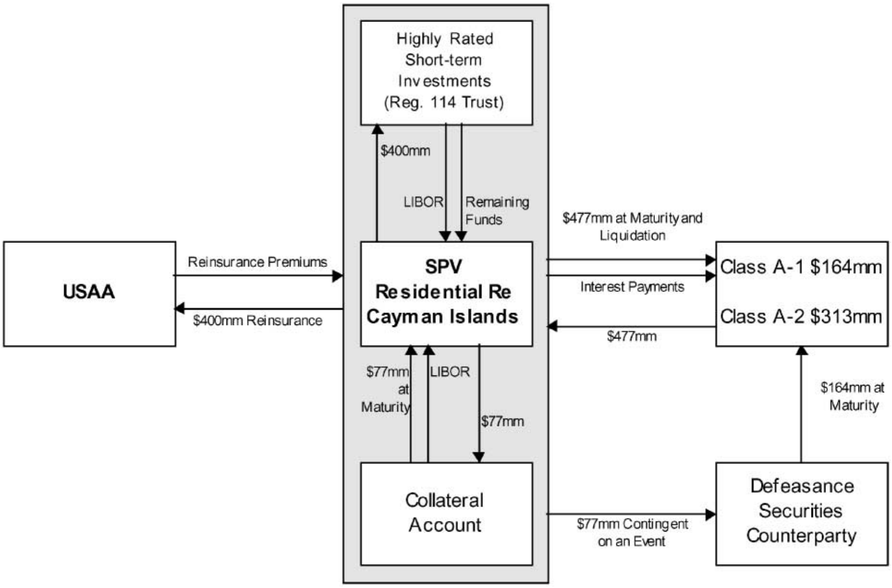
4.3. Residential Re

As Fig. 5 shows, the top-most layer in 1997 was reinsured through the capital markets using an independent, special purpose reinsurer called Residential Re. Residential Re's sole purpose was to be an efficient provider of reinsurance to USAA; it would do no other business. For tax and regulatory reasons, the company needed to be run entirely independently of USAA. Residential Re provided a one-year reinsurance contract to USAA, covering large hurricanes that struck between the dates of June 16, 1997 and June 14, 1998. (See Fig. 6 for a time-line.)

At a high level of generality, the reinsurance contract issued by Residential Re was very similar to a typical reinsurance contract underwritten by traditional reinsurers. The most important difference was, in Goldberg's view, that USAA was developing a competing source of risk-bearing capacity, one that would ultimately provide for lower prices and more reliable availability.

At a more detailed level, the reinsurance contract written by Residential Re differed in several respects from those commonly written by reinsurers. The first difference was that the contract covered a single event only. USAA would have the right to choose one, and only one, event from the risk period. Typically, reinsurance contracts covered losses for any number of events that breached the retention, until the limit was exhausted. The second difference concerned credit risk. Residential Re's sole purpose was to write a single reinsurance contract for USAA. It would dedicate collateral equal to the contract limit. As a result, there

[13] See Goldberg (1997).



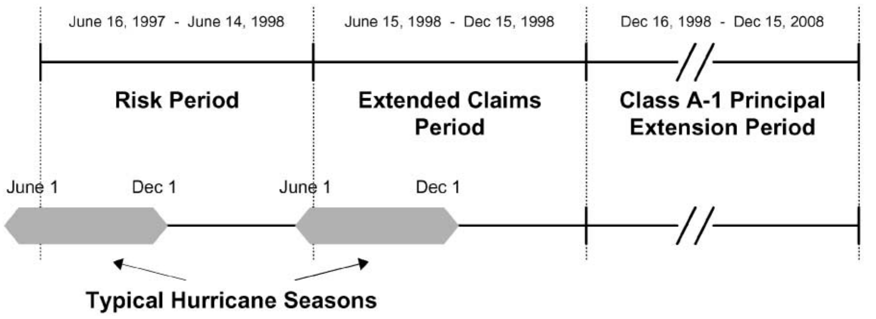


Fig. 6. (a) Structure of the 1997 residential Re transaction. *Source:* Goldman Sachs. (b) Time line for residential Re contracts. *Source:* residential Re offering memorandum.

was virtually no chance of default once a claim against the contract was made. Traditional reinsurers did not fully collateralize individual contract limits, and therefore would default on their reinsurance obligations in sufficiently dire states of nature.[14]

Residential Re agreed to reimburse 80% of USAA's single-event cat losses between $1 billion and $1.5 billion, making the reinsurance contract limit $400 million (0.8($1.5 billion–$1.0 billion)). To collateralize this $400 million

[14] For additional details on the Residential Re contract, see Froot and Seasholes (1997).

limit, Residential Re sold A-1 and A-2 notes. The A-2 notes, totaling $313 million, had their entire principal at risk – a sufficiently large hurricane would result in no principal recovery. Thus, if an event resulted in USAA losses exceeding $1.5 billion, USAA would receive the $313 million of A-2 noteholders' principal.

The A-1 notes were slightly more complicated, as they blended part of an A-2 note with a Treasury strip. This latter feature provided the A-1s with principal protection. Specifically, $164 million in A-1 notes were sold. The A-1 principal was then divided in two parts. The first part was $87 million, which effectively went toward the purchase of A-2 notes. The remaining $77 million went toward the purchase of 10-year US Treasury strips with a maturity value of $164 million if an event occurred. The strips allowed A-1 holders to receive full principal repayment regardless of what happened.[15] This meant that the first $87 million would sustain losses pari passu with the A-2 notes. Thus, between the A-1s and A-2s, reinsurance collateral of $87 million + $313 million = $400 million was available from Residential Re to pay USAA's admissible event losses.[16]

In return for the reinsurance, USAA agreed to pay Residential Re $24 million, or 6.0% of the limit. After fees, noteholders received LIBOR plus 576 basis points for putting funds at risk. Thus, A-2 and A-1 holders received fractions (313/400 and 87/400, respectively) of the premium based on capital at risk. For every dollar noteholders put at risk of a one-year cat-event loss, they took out 5.76 cents in guaranteed premium.

4.4. Actuarial probabilities

The risk of loss to the Residential Re reinsurance contract was modeled by Applied Insurance Research, Inc. (AIR), one of several independent firms

[15] There was a slight complication in the $77 million A-1 notes. If no event occurred, the $77 million paid off as though it was invested in 1-year Treasury bills. This amount, when combined with the $87 million in cat-exposed principal, gave a total of $164 million in principal returned to the A-1 notes in one year's time. However, if a sufficiently large event occurred, the $87 million in cat-exposed principal went to the insurer, not the investor. At the same time, the $77 million would be swapped into 10-year Treasury strips, so that the $164 million in total principal would be covered entirely by the $77 million collateral, but only in 10 year's time. A small fee is paid to a financial intermediary that guarantees the availability of a swap into the 10-year strip at preset prices during the year.

[16] In order to have time to process insurance claims for disaster victims and therefore to determine the extent of USAA losses, Residential Re notes featured a six-month extended claims period. If no event occurred, the due date of the notes was June 14, 1998 – a 1 year maturity. If an event did occur, however, USAA could elect to extend the notes' maturity until December 15, 1998. During this time, USAA was to pay Residential Re an additional half-year's premium. The reinsurance contract, however, was not similarly extended. Thus, if USAA elected to extend the notes, it would pay 1.5 years of premium for 1 year of risk protection.

P Annual Probability that USAA Losses are Greater Than Amounts in Column 3 (1)	1-P (2)	Total Losses (not additive) (3)	Home Owners (4)	Dwelling (5)	Condos (6)	Renters (7)
10.00%	90.00%	$ 242	$ 200	$ 20	$ 8	$ 6
5.00%	95.00%	400	332	32	16	10
2.00%	98.00%	674	552	50	33	18
1.00%	99.00%	986	820	66	55	29
0.96%	99.04%	1,004	831	68	58	29
0.40%	99.60%	1,464	1,180	92	95	43
0.39%	99.61%	1,496	1,216	93	95	43
0.20%	99.80%	1,845	1,555	119	138	61
0.10%	99.90%	2,507	1,962	157	184	90

Graph of Above Data

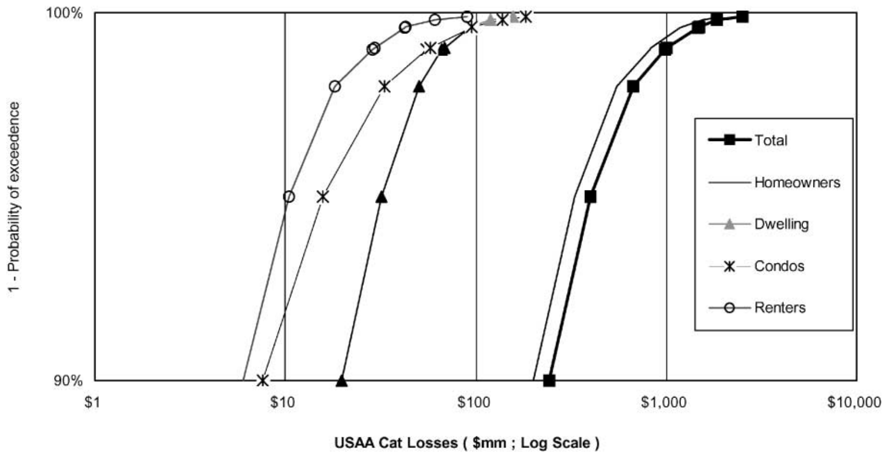


Fig. 7. Estimated probabilities of hurricane losses for USAA ($mm – from simulations). "1 − *P*" in column two and on the graph's *y*-axis represents 1 − probability of exceedence, the annual probability that a catastrophic loss suffered by USAA will be less than the corresponding amount shown in column three and on the *x*-axis of the graph. Source: USAA.

specializing in the probabilistic modeling of catastrophic events. AIR developed a probability distribution of losses for USAA's specific portfolio on insured homes and autos, shown in Fig. 7. AIR estimated that the Residential Re layer had a 97 basis point probability of exceedence and a 39 basis point probability of exhaustion. The expected loss for the layer (i.e., the integral of the probability of a given loss times the associated loss of principal) was estimated to be 63 basis points.

As in the case with the aggregate premiums, estimated expected losses are small compared to the premium. In equilibrium with perfect markets, we would expect such a zero-beta risk to have an expected return equal to the riskfree rate.

This implies that the theoretical spread over LIBOR for the cat-event risk in the Residential Re layer would be 63 basis points, fair compensation for the expected loss. However, in return for putting capital at risk, investors received $576/63 = 9.1$ times expected loss.

When the issue came to market, it attracted considerable interest. The notes were approximately three times oversubscribed. In the days following the issue, the yield fell from 576 basis points to the mid-400 s, suggesting that there was indeed excess demand. This is particularly impressive, considering how new and untested bonds of this type were.

It also appeared that investors were not the only ones interested in providing USAA's reinsurance capacity. There were unconfirmed rumors that a major cat reinsurer had attempted to undercut the bond offering by promising to write the full reinsurance contract for a lower premium, without the additional expenses or complications created by these untested bonds.[17]

4.5. CEA 1996

Undercutting by a traditional reinsurer of a proposed cat bond offering had happened before. Indeed, comments by market participants suggest a pattern of such behavior. In 1996 the State of California created an entity, the California Earthquake Authority (CEA), to help insurance companies finance potential earthquake losses. In November 1996 the CEA announced that it had decided to purchase reinsurance from National Indemnity, a subsidiary of Berkshire Hathaway. National Indemnity is one of the world's largest reinsurers and easily the biggest single reinsurer of "super-cats" (high incidence, low probability cat layers).

A purchase of traditional reinsurance was not, however, the expected outcome. Over the prior year, California's insurance commissioner had solicited detailed proposals from investment banks for a CEA cat bond, and had chosen a lead bank for the bond's issuance. This proposed CEA bond offering was similar to the Residential Re transaction, though it was more than double its size. A CEA bond would have attracted considerable attention as a watershed transaction. However, the bond transaction did not materialize. Just as the investment bank's underwriting mandate was to be signed, National Indemnity intervened, undercutting the proposed bond's premium. The offer was particularly unusual given that the limit exceeded $1 billion, well in excess of what a typical reinsurer would assume in a single transaction.

Why did National Indemnity undercut this transaction? Under the structure of CEA's four-year reinsurance contract with National Indemnity, the expected

[17] Based on a private communication with Christopher McGhee, Managing Director, Marsh McLennan Securities Corp.

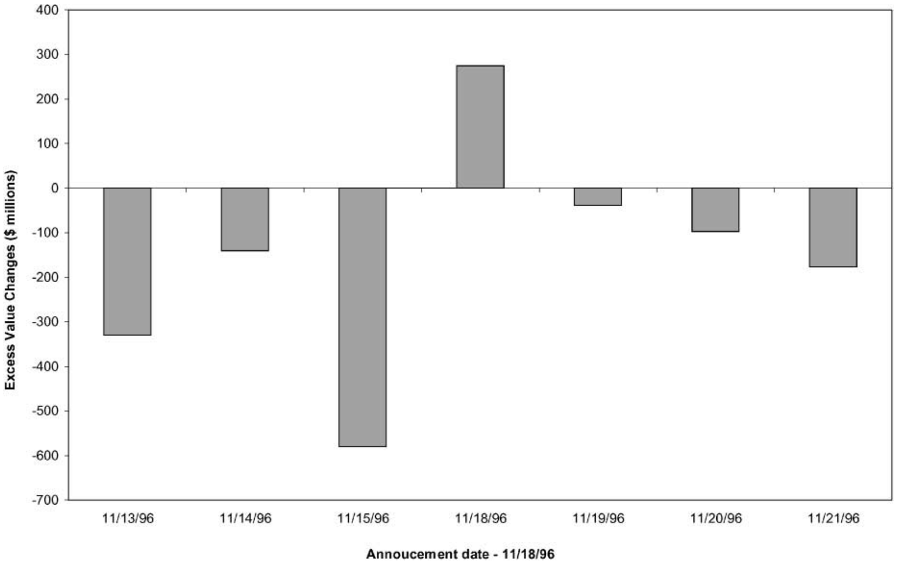


Fig. 8. Changes in Berkshire Hathaway's market value (in excess of the market). Graph shows the value of the percentage excess return of Berkshire Hathaway's market capitalization in excess of the S&P 500. Announcement date is the first day on which news of National Indemnity's reinsurance contract with the California Earthquake Authority is reflected in the closing stock price.

loss was 1.7% and the limit $1.05 billion. In return for bearing the earthquake risk, National Indemnity would receive an annual premium of $113 million – or 6.3 times expected losses of $18 million.[18] In fact, the terms were slightly better, as the contract called for Berkshire Hathaway to receive all four annual premiums in the first two years. Since the $1.05 billion limit aggregates over the four-year period, the gamble effectively amounted to Berkshire putting up about $600 million in downside exposure for a 93.4% chance to make about $400 million in premium and only a 6.6% chance of losing the $600 million.[19]

Berkshire Hathaway's shareholders seemed to agree that the CEA contract was a windfall for their firm. As Fig. 8 demonstrates, the contract announcement appears to have increased Berkshire's stock market valuation by almost $300

[18] The average annual premium for the four-year aggregate cover was 10.75% of the annual limit, whereas the likelihood that the reinsurance is triggered was 1.7%, according to EQE International, a catastrophe risk modeling firm. This yields $10.75/1.7 = 6.3$ premium times expected loss.

[19] Based on a probability of 1.7% per year, the chance of no event over the four years is $(98.3\%)^4 = 93.4\%$. Data in this paragraph are from *IBNR Insurance Weekly* (Volume III, #46), Dowling & Partners Securities, LLC.

million, or 75 basis points in excess of the broad stock market change.[20] It appears that the CEA reinsurance contract (and other contracts that might follow) were priced well above "fair" value.[21]

While information on Berkshire Hathaway's bidding strategies is understandably sketchy, market participants acknowledge repeated interventions in undercutting potential capital market transactions. For example, recently rumors suggest that Berkshire Hathaway again underbid successfully a potential $250 million cat bond issue by XL, a major Bermudan reinsurer. The bond issue was well along, but Berkshire Hathaway made an eleventh-hour offer to provide all of the capacity in return for a premium that was below the cat bond costs to XL.[22]

4.6. Residential Re 1998 and 1999

In 1998 and 1999, USAA purchased reinsurance contracts from incarnations of Residential Re that were nearly identical to that of 1997. The structure of the reinsurance to USAA had evolved, but only slightly over time, with differences summarized in Table 2. On the financing side, all of the 1998 and 1999 notes were like the 1997 A-2s, in that all principal was at risk. There was therefore no need for a Treasury strip or defeasance mechanism in the 1998 or 1999 programs. The exposures covered by the policy were essentially the same, as USAA's underwriting profile changed only marginally during this time.

Perhaps the most important difference in the notes was the amount of USAA paid investors for providing reinsurance capacity. Premiums fell from 5.76% in 1997 to 4.12% in 1998 and to 3.66% in 1999. Although not as well publicized, there was a decline in expected loss as well. As Table 2 shows, the expected loss rate stood at 63 basis points in 1997; this fell to 52 basis points in 1998 and 44 basis points in 1999. Because expected losses declined, the ratio of premium to expected loss fell by less than premiums – from 9.1 in 1997 to 7.7 in 1998 and 8.3 in 1999.

The decline in expected loss appears surprising at the outset. During this period, property values and construction prices rose somewhat, and there was a slight increase in the number of units USAA insured. Thus, based on exposures

[20] The contract announcement by Berkshire Hathaway occurred on Friday 11/15/96, after market close. On Monday, 11/18/96, Berkshire's class A shares closed at $33,200, up from Friday's close of $33,000 (total equivalent class A shares outstanding were 1,210,762). Over the same period, the S&P 500 fell from 737.62 to 737.02.

[21] Fig. 8 shows a negative excess return in the days preceding the announcement, with an especially large negative excess return on the day prior to announcement. It is possible (but I believe extremely unlikely) that this was caused by the combination of early leakage of the news prior to the announcement and the news being interpreted negatively by the market.

[22] Private communications with reinsurance brokers and investment bankers from Guy Carpenter, Goldman Sachs, and Marsh McLennan Securities. Thanks to Christopher McGhee for bringing this to my attention.

Table 2
Residential reinsurance transaction comparison[a]

Issue	1999	1998	1997
Exceedence loss	$1.0 billion	$1.0 billion	$1.0 billion
Exhaustion loss	$1.5 billion	$1.5 billion	$1.5 billion
Risk capital	$200 million	$450 million	$400 million
Premium	3.66%	4.13%	5.76%
Expected loss	0.44%	0.52%	0.63%
Premium/expected Loss	8.3	7.9	9.1
Attachment probability	0.76%	0.87%	0.96%
Exhaustion probability	0.26%	0.32%	0.42%
USAA coinsurance	10%	10%	20%
Coverage period	52 weeks	50 weeks	52 weeks
Extended claims period	6 months	6 months	6 months
Defeasance period	Not applicable	Not applicable	10 years
Interest payments	Quarterly	Quarterly	Monthly
S&P rating	BB	BB	BB

[a] *Source:* Residential Re-offering memoranda.

Table 3
Effect of AIR model updates on USAA expected losses[a]

(a) Estimated annual occurrence losses ($ millions) (12/31/98 exposure, no demand surge included)

Estimated Probability of occurrence	1997 model	1999 model	% Change in losses
200 basis points	$600	$564	− 5.9%
100 basis points	$831	$751	− 9.7%
40 basis points	1,239	1,066	− 14.0%
20 basis points	1,431	1,377	− 3.8%
10 basis points	1,776	1,603	− 9.8%

(b) Effect of demand surge changes estimated annual occurrence losses ($millions) (12/31/98 exposures, 1999 models)

Estimated probability of occurrence	Using 1997 demand surge function	Using 1999 demand surge function	% change in losses due to changes in demand surge
200 basis points	654	641	− 2.0%
100 basis points	868	849	− 2.2%
40 basis points	1,283	1,240	− 3.4%
20 basis points	1,689	1,633	− 3.3%
10 basis points	2,039	1,962	− 3.7%

[a] *Source:* Residential Re-offering memorandum, May 1999.

alone, there was an increase of approximately 5% in the expected loss for a 1%-likely event from 1997 to 1999. The main reason for the decline was therefore not a change in exposure, but a set of incremental changes made to the AIR model. The overall effect of these is shown in Table 3. Changes were made in the way the model generates events, event paths, and geographic windfield speeds. Changes were also made in the way the model estimates damageability from high winds and storm surge, and estimates the demand surge (i.e., the additional costs due to relative scarcity of contractors, materials, etc. in the aftermath of a storm). These changes were important in that use of a given AIR model for all years would show an increase (rather than a decrease) in exposure and expected loss.[23]

It is also interesting to note that the 1999 Residential Re contract limit was smaller, $200 million versus $400 million and $450 million for the 1997 and 1998 programs, respectively. For the 1999 renewal, USAA supplemented the Residential Re contract by purchasing a nearly identical reinsurance contract for $250 million from traditional reinsurers. Thus, between these two contracts, USAA in 1999 again covered $450 million (i.e., 90%) of its single-event losses between $1.0 billion and $1.5 billion. USAA thus used the twin-sources of capacity alongside one another to furnish low-probability reinsurance capacity.

It is likely that USAA divided its 1999 coverage for several reasons. First, by splitting the program, USAA may have stimulated greater competition between the traditional reinsurance and cat securitization markets. Overall program costs would fall further by instituting such a split. Given the extent to which premiums for traditional reinsurance have fallen over time (see the discussion below), there is a concern that capital markets premiums would not otherwise decline as quickly.

There is some evidence to support the competition argument. The premium paid by USAA for the $200 million 1999 Residential Re program was 3.66% received by investors, plus 0.21% for a swap to deliver LIBOR and for minor day-count adjustments (excluding fees). At the same time, USAA locked in a nearly-equal premium rate on the $250 million traditional reinsurance portion of the 1999 program. This experience differed from that of earlier years. In both 1997 and 1998, it was rumored that USAA paid more for the Residential Re program than it would have for traditional reinsurance. (Note this comparison does not take into account the differences in credit quality between a collateralized special purpose vehicle and a standard reinsurance company, nor does it take into account the additional fees required for the bond-financed program.) While paying more may have been justified as an investment in

[23] See Residential Reinsurance (1999) for more details. It is unclear which version of the model should be used to evaluate each year's expected losses. We apply the version of the model that was current for each year of the program. This assumes that the market thought the expectation of future revisions was zero.

developing the capacity of the capital markets, the returns on further investments of this kind are likely to be low.

Second, while the 1997 and 1998 Residential Re notes were oversubscribed, there was some concern about whether the same would be true in 1999. Large portions of the 1997 and 1998 programs were purchased by two large institutions. One of those dropped out in 1998, but the other, a single large hedge fund, reportedly increased its purchase substantially that year. However, this hedge fund experienced severe financial difficulties in the late summer and fall of 1998 and was unlikely to participate in 1999. These developments, coupled with the lower reinsurance market premiums, may have led to concerns about the success of a full $450 million issue of 1999 Residential Re notes.

4.7. Summary

Our evidence suggests that the ratios of premium to expected loss for USAA and CEA are similar to those paid on average in the industry, particularly for the higher layers.[24] Even though the methodologies for computing expected loss differ (third party models for USAA and CEA versus the Froot and O'Connell model of the industry aggregates), the basic conclusion is the same: premiums are a multiple of what they should be according to fair pricing.

The empirical evidence also shows a pattern of purchases across event sizes that is similar for USAA and the aggregate purchase profile shown in Fig. 2 (although USAA currently purchases reinsurance for much larger events than the 1994 norm for the industry). This is not the optimal profile predicted by the theory, which suggests that the lowest probability events are the most valuable to reinsure. However, neither insurers in the aggregate nor USAA in particular purchase coverage for extremely low-probability events.

The discussion in the clinical section has also given us a clearer sense of reinsurance market dynamics, both in terms of access to capital and in bidding. In the next section, examine the aggregate and clinical data further in order to understand why prices appear so high and demand for reinsurance appears so low. We identify and enumerate underlying explanations for our findings thus far and for the rejection of the basic theory.

5. Failures of the theory: explanations and interpretations

Our explanations are of two types: those that affect supply and those that affect demand. Taking the two findings above as given – that reinsurance quantities are low and prices high – naturally suggests some form of supply

[24] Although not included in the Guy Carpenter database, the Residential Re and CEA layers above would fall into deciles 9 or 10 in Fig. 4.

restriction. However, there is unlikely to be a single explanation, and several demand-related explanations appear to be supported by some of the evidence as well. Thus, we consider factors that affect both demand and supply. Parts of this next section draw upon Froot (1999).

5.1. Explanation 1: insufficient capital in reinsurance

Perhaps the supply of reinsurance at high layers is low because catastrophic risk-taking capital is somehow inhibited. In other words, reinsurers themselves may face financing imperfections similar to those faced by insurers in the Froot et al. (1993) model above. The situation where both insurers (i.e., hedgers) and reinsurers (i.e., financial intermediaries) face financing imperfections is modeled by Froot and O'Connell (1997). In this case, reinsurers will bear cat risk only if they are compensated for the incremental financing imperfections imposed. So cat risk capacity will be expensive compared with fair value.

The appearance of capacity shortfalls, even relatively temporary ones, may result from a number of structural mechanisms: it may be costly for existing reinsurers to raise additional funds in the capital markets; it may be hard to find investors who expect appropriately low "equilibrium" rewards for bearing catastrophic risks; it may also be that it is costly for reinsurers to hold large amounts of collateral on their balance sheets. Given that there are several potential mechanisms, we might ask whether there is prima facie evidence that reinsurance capital is in short supply.

First, according to Berkshire Hathaway chairman Warren Buffett, shortages of capital appear to be an important rationale for Berkshire Hathaway's reinsurance strategy and its bidding behavior. In his 1996 letter to shareholders, Buffett observes,

> Our … competitive advantage [in writing "supercat" risks] is that we can provide dollar coverages of a size neither matched nor approached elsewhere in the industry. Insurers looking for huge covers know that a single call to Berkshire will produce a firm and immediate offering.

Perfect access to capital by new and existing reinsurers would remove this "competitive advantage". So it seems Buffett believes in, and pursues a strategy of exploiting, capital shortfalls.

Buffett's strategy is also predicated on a perception that a capacity shortage may become temporarily worse, for example, if reinsurer capital is depleted by a large event. A temporary shortage would be consistent with the post-event cycle suggested by Fig. 3, wherein prices rise and then fall while quantities fall and then rise. Again from Berkshire Hathaway's 1996 annual report, Buffett writes:

> After a mega-catastrophe, insurers might well find it difficult to obtain reinsurance even though their need for coverage would then be particularly

> great. At such a time … it will naturally be [Berkshire's] long-standing clients that have first call on it. That business reality has made major insurers and reinsurers throughout the world realize the desirability of doing business with us. Indeed, we are currently getting sizable 'stand-by' fees from reinsurers that are simply nailing down their ability to get coverage from us should the market tighten.

Buffett seems to be saying that the prospect of a capital shortage in the aftermath of a major cat event motivates insurers to purchase "capacity" protection. Note that this is not protection against an increase in prices – presumably National Indemnity's clients would pay the going market rate – but protection against being excluded from the marketplace. The price of a guarantee to participate in a well-functioning marketplace should be zero.

In both of these quotes, and in other discussions of "supercat" risks in Berkshire Hathaway annual reports from 1995, 1996, and 1997, Buffett emphasizes the value to Berkshire's shareholders of the company's substantial balance sheet. In a world of costless access to external finance, a balance sheet earns no rents by virtue of its size. It therefore ought to bestow no competitive advantage on those who control them.

Buffett's emphasis on quantity shortages, and not price increases, is important for making an argument on financial imperfections. It is consistent with the low level of risk transfer and post-event decline in quantities, both shown in Fig. 2. It also avoids reliance on the price evidence we have seen so far (e.g., Figs. 2 and 3). As we mentioned above, this price evidence can be distorted by unobserved variation in subjective event probabilities (such as those driving the updates in the AIR model). So it is the weakest link in the argument.

However, if we were to test whether prices comove inversely with quantities, in a way that is not subject to the probability-updating critique, we would have more decisive evidence that capacity shifts lie behind price movements and levels. Suppose we were to observe a large hurricane that subsequently increased reinsurance premiums. The probability updating hypothesis would say that the change is due to learning about the future damages associated with hurricanes (fully rational or not) and not to a decline in the supply of reinsurance capital. We would therefore expect the premiums on hurricane risk to rise. At the same time, we would have learned nothing about the probabilities of loss on independent perils, such as earthquakes. Thus, under the probability updating hypothesis, the premiums on earthquake risk in California should remain constant. Alternatively, if the post-hurricane price increase is a result of capital market imperfections, we would expect an increase in both hurricane *and* earthquake premiums. Thus, if we can divide up the post-event cross-section into different peril combinations, we can perform a kind of event study to better test the comovement of prices and quantities.

Table 4
Changes in reinsurance premiums and quantities purchased subsequent to Hurricane Andrew

Comparison of price responses in the year after Hurricane Andrew (8/20/92–8/19/93) for different insurers. Panel (a) contrasts insurers that have high and low exposure to the Southeast (as measured by market share). Panel (b) contrasts insurers that have high and low exposure to hurricanes. The table shows the mean exposure and the mean price change of the five most extreme contracts in each case. The mean price change for the insurers with lesser exposure to the Southeast is calculated using all 14 of the insurers that have zero market share in that region.

	(a) Southeast exposure			(b) Hurricane exposure		
	Mean exposure	Mean $\Delta ln(p_{j,t})$	Mean $\Delta ln(q_{j,t})$	Mean exposure	Mean $\Delta ln(p_{j,t})$	Mean $\Delta ln(q_{j,t})$
5 most-exposed insurers	0.141	0.415	− 0.021	0.184	0.583	− 0.082
5 least-exposed insurers	0.000	0.335	− 0.013	0.112	0.336	− 0.047

Table 4 provides the results of such an event study. The table shows both price and quantity responses in reinsurance purchased during the year following Hurricane Andrew. As before, reinsurance quantity is measured as expected loss. We already know that in aftermath of Hurricane Andrew, reinsurance purchases fell, and that this occurred primarily through an increase in retentions. Table 4 additionally demonstrates that the quantity purchased fell by more, and the premium paid rose by more, for those insurers that had greater exposure to the Southeastern US and to hurricanes wherever they occur.

Thus, across contracts, prices rise most where quantities decline most. It seems hard to explain this fact by a subjective increase in probabilities, provided that the probability increases retain some bearing to the information revealed in the event. Thus, while there may be some probability updating that we cannot capture in our unconditional estimates of expected loss, there also appears to be a strong element of true price increase. This is probably best explained by a temporary, backward shift in the supply of capital.

Of course, it is not surprising that the supply of cat risk bearing capital is temporarily restricted immediately following an event. Large-event losses deplete reinsurer capital and surplus and, realistically, require some time to replenish. However, six years elapsed between Hurricane Andrew and the first declines in the premium-to-expected-loss ratios in Fig. 3. The timing seems consistent with the hypothesis that frictions retard capital flows into the reinsurance sector.

Capital shortages in reinsurance can also explain the pattern of prices shown in Fig. 4, where the highest price-to-expected-loss ratios occur in the lowest-probability layers. To see this, consider an equilibrium in which reinsurers completely share exposures with the insurers, but where there is a limited amount of capital available to both. In such an equilibrium, the lower-probability

event layers will have the highest markup relative to fair value. The simple intuition is that large events are associated with reduced capital for both insurer and reinsurer alike. With capital already low, additional marginal losses are even more costly. As a result, the equilibrium price of reinsurance will correspond to the pattern of insurer reservation prices shown in Fig. 4, with the lowest-probability-event layers having the highest price relative to fair value.

As to the source of these frictions, there are a number of possibilities. One is the literal mechanism behind Froot et al. (1993) – that the deadweight costs of financial distress are increasing and concave in the amount of external finance used. However, the costs of external finance need not be driven by financial distress alone. Adverse selection and agency issues may lead providers of external capital to charge more after poor performance and less after better performance, as they update on quality of the manager or investment strategy (see Shleifer and Vishny, 1997). If capital providers cannot clearly separate performance into event losses and reinsurers' skill in peril selection, then the cost of capital provided to reinsurers would rise after events and fall after no events. The history of opacity in the reinsurance market provides some support for this view, in that it is difficult to find appropriate, transparent performance benchmarks to evaluate reinsurance portfolio managers (i.e., reinsurers).

Another mechanism that forces the required return on capital to vary through the event cycle is investor 'trend following.' Specifically, suppose some investors expect recent performance to continue, so that they tend to buy exposures that have recently performed well and to sell those that have not. Such an expectation would not be rational when applied to cat event risks. Yet it would also tend to increase the supply of capital to reinsurance after a non-event period, when prior returns have been high, and to decrease the supply of capital to reinsurance following an event.

We can't directly measure the contribution that such irrational investor behavior made to the cat price cycle of the 1990s. However, Berkshire Hathaway's stock-price response to the CEA reinsurance contract suggests the contribution is not large. If the high reinsurance prices in the mid-1990s were driven by high investor hurdle rates, then investors would not have perceived the CEA transaction to have added approximately $300 million in market value to Berkshire Hathaway.

The final point in this section is that there is a kind of irony in the financing imperfections story as applied to insurance and reinsurance: much primitive cat risk could be reduced through investments in mitigation, investments that would appear to pay high actuarial returns.[25] However, many of these invest-

[25] Examples of mitigation would include changes in building codes and zoning restrictions which would apply across many homes and buildings.

ments are not made – indeed, many observers consider the paucity of mitigation investment a puzzle. One explanation for this is that risk mitigation means upfront expenditures that would require individuals and corporations to deplete scarce internal capital or to raise external capital. Thus, capital market shortages may in part be responsible for the size of the catastrophe risk pool. Without capital shortages, reinsurance capacity would be greater, but there would also be fewer risks to reinsure in the first place.[26]

To conclude, Buffett's explanation for the post-Hurricane-Andrew decline in premiums is perhaps the strongest piece of evidence for capacity shortages in the reinsurance market:

> Many investors who are 'innocents' – meaning that they rely on representations of salespeople rather than on underwriting knowledge of their own – have come into the reinsurance business by means of purchasing pieces of paper that are called 'catastrophe bonds.' … The influx of 'investor' money into catastrophe bonds – which may well live up to their name – has caused super-cat prices to deteriorate materially.

Clearly, Buffett believes that capacity expansion is the cause for the decline in premiums. And this is exactly what USAA was attempting to achieve with the creation of Residential Re. Buffett's claim that capacity expansion has resulted from misinformation rather than better risk sharing is understandable, but less than fully credible. As we have seen, investors in USAA's cat bonds have been paid handsomely for their contribution to reinsurance capacity, in both an ex ante as well as an ex post sense. Indeed, it appears that Buffett's shareholders would have very much wanted the business. And, ironically, it is unclear whether they ultimately got it: rumors were that a number of reinsurers bought the Residential Re bonds for their own investment portfolios

5.2. Explanation 2: reinsurers have market power

A number of observers have suggested that the empirical evidence above might be explained by market power rather than by a capital shortage per se. Under this explanation, prices rise and quantities decline not because reinsurance capital is impossible or costly to obtain, but because existing reinsurers have no incentive to increase their capital. By putting less money at risk and preventing new entry, incumbent reinsurers keep prices high. Some observers, such as James M. Stone of Plymouth Rock Company (a former Harvard professor of economics and Massachusetts Insurance Commissioner), argue that market power among reinsurers is the main reason that catastrophe reinsurance has proved more profitable than insurance.

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[26] See Kunreuther and Kleindorfer (1999).

Of course, it is very hard to provide evidence that market power among reinsurers has increased secularly over time or merely cyclically in the aftermath of events. There is a general view that the reinsurance industry has been consolidating. There has been a distinct drop, for example, in the number of Lloyd's syndicates since the 1960s and 1970s. There has also been an increase over time in the capital and market share of large reinsurers. However, these facts aren't necessarily associated with increased market power in setting prices or restricting supply. For example, even though there are fewer Lloyd's syndicates, catastrophic risk pricing is not typically determined by individual syndicates.

Furthermore, while consolidation has occurred in the industry, greater market power need not be the driving force. Consolidation may result from economies of scale. The information-intensity of reinsurance is one possible source of scale economies. For example, there may be high fixed costs of developing analytic capabilities and systems.[27] Once these systems are in place, optimal reinsurer size grows as the required investment in fixed-cost systems increases. Consolidation may also be an efficient industry response to costs of obtaining outside capital. If those costs are partially fixed, or decline proportionately with size, the amount of outside capital may also be a source of increasing returns.

Barriers to entry are another place to look for market power. Clearly, the barriers to buying Residential Re's cat bond are lower than the barriers to underwriting reinsurance. Even so, there is considerable evidence of entry into traditional reinsurance in the 1990s. For example, beginning in 1993 at least six major reinsurance companies were formed in Bermuda, representing over $7 billion in new reinsurance capital. While the barriers to entry may be high for some agents (e.g., individual or institutional investors), Bermuda is evidence that the barriers are not uniformly high for all groups.

Still, it is interesting to speculate about the role of market power in the steep price decline shown in Fig. 3, near the time of Residential Re's first cat bond offering. During this time, little new capital was injected into traditional reinsurers. Although reinsurer balance sheets grew with premiums and interest, while experiencing trivial event losses, the same was true for each year since 1994. Similarly, USAA's cat bonds issued in 1997 and 1998 may have been innovative, but they accounted at most for only a tiny fraction of total cat reinsurance treaties (based on limit). Thus, it is not clear that increases in capacity can explain price behavior.

However, a lesson of USAA is that premiums are driven by the contestability, rather than the capacity, of the reinsurance market. Buffett's strategy to undercut USAA's and others' cat bonds is direct evidence that the market has become more contested. Note this is true even if Buffett succeeds in winning business

[27] Comments by Stewart Myers, in Froot (1999, pp. 434–437).

from the bond placements. The point is that cat bonds unleash a reduction in the barriers to entry into reinsurance. And it is barriers to entry, not the amount of capacity in current use, that explains deviations from fair pricing.

Buffett's final remark in the previous subsection seems to recognize this point. It assigns disproportionate importance to cat bonds, which at most account for only a small fraction of the reinsurance market. It is hard to imagine why Buffett would go out of his way to acknowledge (and discredit) other sources of cat capacity when they are of such small size unless they threaten existing reinsurers' market power.

It seems that a good test for distinguishing between the market power and other supply side hypotheses would be to ask, 'Did Buffett wind up writing reinsurance on less attractive terms as a result of CEA, USAA and other attempted cat bond issues?' If the answer were "yes", it would suggest that the price of reinsurance was above marginal cost, i.e., that reinsurers have market power. If the answer were "no", it would support stories in which there is perfect competition, but high marginal costs of reinsurance. We have already discussed one of these explanations, that of costly access to external capital. However, there are other stories that generate high marginal costs. We explore these further in explanations 3–5 below.

5.3. Explanation 3: the corporate form for reinsurance is inefficient

Under this explanation, the organizational form of reinsurers is unnecessarily costly: i.e., National Indemnity is a less efficient corporate structure than is Residential Re. Observers of corporate governance often point out that it is costly to give discretion to managers. Managers with discretion can pursue objectives other than value maximization. It may be difficult for shareholders to identify and discipline this behavior. Even if most managers are benevolent, the prospect that a bad manager might use his agency relationship against shareholders reduces stock prices and drives up the cost of capital. The special purpose structure of Residential Re substitutes rules and a trustee for management, thereby virtually eliminating discretion.

This generic corporate finance argument of "agency costs" has application in a number of ways here. First, it clearly can be applied to reinsurers. The details of a reinsurer's practices and the specific contracts it underwrites are not transparent to arm's-length capital providers. And, given the occasional-big-loss nature of reinsurance, it takes many years to evaluate management efficacy and true business profitability. In reinsurance, managers may have an unusually large incentive to gain market share (and increase their size) by cutting premiums beyond that called for by shareholder value maximization.

The cost of delegating discretion to managers of opaque firms is difficult to assess, but can be partially determined by considering some narrowly-defined

businesses, such as closed-end funds. These funds invest in publicly traded securities and then sell stakes in their portfolio to shareholders, much as mutual funds do. However, unlike "open-ended" funds, closed-end-fund portfolios are not affected by fund purchases or redemptions; shareholders buy and sell shares among one another, without the fund involved. Thus, the price of the closed-end-fund shares, like the price of most traded stocks, must find its own value in the marketplace in accord with supply and demand.

As is well known, there is a puzzle associated with closed-end fund shares: their prices are, on average, considerably below their net asset values.[28] This cannot happen with open-ended-fund shares. Closed-end share discounts average about 10–20%, and are fairly pervasive across funds and over time. It is often argued that agency costs account for these discounts. The story is that closed-end funds must pay an average return to shareholders in excess of the fair return on the underlying net assets. The reason is that shareholders can't directly observe or discipline managers and are concerned that managerial decisions put the managers' interests above those of shareholders.

The agency cost argument may explain why the costs of reinsurance capital, and by inference, reinsurance prices, are high. The argument is buttressed by two regularities. The first is that reinsurance managers regard their capital costs as "equity-related," i.e., as requiring a return considerably above US Treasury rates. Fair premiums on cat reinsurance contracts are therefore beneath the hurdle rate imposed by shareholders. Yet, given that catastrophe risks are uncorrelated with those of other financial assets, shareholders' required returns on cat risk should, as argued above, be low. Agency costs may be one factor forcing up shareholder required returns.

There is a second regularity behind the view that reinsurers are an inefficient corporate form. Even without agency costs, there is evidence that shareholders expect reinsurer equity returns to be well above US Treasury rates. Evidence for this comes from the behavior of stock prices of public Bermudan reinsurers, such as Mid-Ocean Ltd. (recently purchased by XL), Renaissance Re, and Partner Re. These firms hold large property/catastrophe liabilities, and historically have held assets in the form of short-term notes and bills. Neither their assets nor liabilities are correlated with the stock market, yet their share prices comove positively with the stock market. Specifically, a 10% increase in the level of the S&P 500 is associated with an increase in the average value of these firms of about 6.5%. We cannot identify a source of this comovement that emanates from the companies themselves.

While it is interesting to speculate on the source of this distortion (e.g., noise, liquidity, etc.), the point here is to ask how reinsurance managers ought to respond. Clearly, investors should require a higher return on these stocks if their prices will move with the market. And, as a result, value maximizing reinsurance

[28] See Lee et al. (1991) for a general discussion of the closed-end-fund puzzle.

managers should inherit higher hurdle rates, setting premiums above actuarial value.[29] This argument suggests that equity-financed reinsurance may be inefficient even in the absence of agency costs. If equity capital requires a high return, and reinsurer assets and liabilities contain no broad equity market risks, then equity is an expensive form of capital. And if reinsurance is financed in an expensive manner, reinsurance prices will be high.

However, former J.P. Morgan Vice Chairman Roberto Mendoza takes a different view, observing that Bermuda's zero rate of corporate income tax reduces reinsurers' costs of equity. With no income tax, reinsurers would gain little by substituting debt for equity finance, since there are no interest tax deductions available to them in the first place. Furthermore, Bermudan reinsurers provide shareholders with an opportunity to achieve tax-free compounding on invested capital. This tends to lower the cost of equity relative to what it would otherwise be.

Mendoza also argues that managerial discretion may provide an "agency benefit" in the case of cat reinsurance. In a highly inefficient and specialized market, shareholders need an experienced agent to identify underwriting opportunities. In this case, the present value of the managerial discretion is positive, since it allows shareholders to exploit reinsurance market inefficiencies.

If true, Mendoza's arguments suggest that the corporate form of reinsurers, particularly those in Bermuda, is actually a highly efficient delivery mechanism for reinsurance risk.

Can we learn anything from our clinical data about the actual efficiency of traditional versus special purpose reinsurers? One fact that stands out is that both the CEA and Residential Re tranches were low-probability, large-event layers (both had annual exceedence probabilities that were less than 2%). This suggests that the relative efficiency of the traditional corporate reinsurer is weakest for the highest layers. This is also consistent with the lack of transparency of traditional reinsurers' underwriting portfolios making it particularly difficult to evaluate reinsurers that have written very low-probability protection. Those that write protection for more every-day types of losses achieve results that are more dependably normally distributed. There is less scope for an extreme left-tail loss to be hiding in the results. Investors may well charge a higher required return for this kind of opacity. This creates a motivation to warehouse low-probability contracts in more transparent special purpose vehicles instead of in traditional reinsurers' opaque books.

[29] Of course, if it were feasible, the first-best response would be to remove the underlying distortion altogether. If, for example, the market exposures of the stock prices were immutable and fixed, then it would be best for managers to increase the equity exposure of their assets, so that the firms' true asset betas corresponded with the fixed betas assigned by the market. Then there would be no need to increase the hurdle rate on cat reinsurance. Alternatively, managers could potentially substitute debt finance for equity to avoid the "high" costs of equity.

5.4. Explanation 4: the frictional costs of reinsurance are high

This explanation says that prices are high because, as financial instruments, reinsurance contracts are illiquid, have high transactions costs, brokerage, etc. These sources of friction imply that there are important costs in getting capital and reinsurance contracts together in a repository called a reinsurer.

There is abundant evidence that illiquid assets trade at significant discounts. Letter stock, as one example, typically trades at discounts of 25% versus publicly-traded stock; on-the-run bonds trade at significant premiums versus less liquid off-the-run bonds; and so on. However, illiquidity of one-year reinsurance contracts is not enough to drive up the hurdle rates of the reinsurers who write them. Reinsurers' hurdle rates should be determined by reinsurers' own costs of capital, so the illiquidity would need to drive up the cost of their own placements. This may arguably have been the case for Lloyd's commitments from individual names; it is far less compelling for publicly traded reinsurers in Europe, the US, and Bermuda.

Other frictions, such as brokerage costs and servicing expenses, can legitimately raise the cost of procuring reinsurance. However, these costs are not out of line with other financing charges. For example, in the National Indemnity transaction described above, annual brokerage fees were less than 1% of premium, and therefore, were about 11bp of limit. If the reinsurance had been issued as a capital market instrument, as had been anticipated by some, these costs would have amounted to about 5% of annual premium, or approximately 55bp of limit. In fact, the fees associated with 1997 Residential Re bond offerings came to approximately 100bp of limit.[30] Thus, if anything, the traditional reinsurance brokerage and issuance expenses are lower than standard capital-market fees.

Furthermore, the high level of prices seems well above anything that can be explained by brokerage and underwriting costs. Even if brokerage and underwriting expenses had come to a high of 10% of premium in the National Indemnity deal, complete elimination of these expenses would have driven down the multiple of premium relative to expected losses by about 0.6 from 5.3 to 4.7. Brokerage and underwriting expenses cannot explain observed price levels.

Another kind of frictional inefficiency is the means by which reinsurers manage risk. Reinsurers manage their risk by aggregate (notional) limits, rather than exposures. For example, a reinsurer might decide it will risk up to $100 million on Florida, but without specifying the distribution of Florida losses on contracts written, or the covariance of Florida losses with potential losses on its North Carolina contracts. Removing such portfolio inefficiencies could have a substantial impact on the cost of risk transfer.

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[30] See Moore (1998).

Better reinsurer risk allocation can reduce the cost of capital if reinsurers face financing imperfections, as in explanation 1. A poorly diversified portfolio of reinsurance adds needlessly to risk, and risk to internal capital is costly if there are financing imperfections. As a result, there is a kind of interaction effect between this explanation and explanation 1 above: costs of external finance can magnify the impact of poor diversification on reinsurer capital costs. This might be a more promising place to look for frictional inefficiencies in reinsurance intermediation, but only if one accepts the notion of financing imperfections in the first place.

5.5. Explanation 5: markets are degraded by moral hazard and adverse selection

Moral hazard and adverse selection are often singled out as distortions that prevent markets from functioning efficiently. In general these distortions suggest that risks should be disproportionately born by those who control them and/or know them best. Clearly, these effects restrict reinsurance supply. So they may help explain some of the facts we observe.[31]

Market participants also claim that there is evidence for the presence of moral hazard and adverse selection in reinsurance markets. Often an explicit reinsurance contract contains an implicit agreement that reinsurers will charge more in the aftermath of a claim and that the cedent will continue in the future to buy reinsurance from the same underwriter. Under this interpretation, property/catastrophe reinsurance is an implicit form of "finite" reinsurance. Finite reinsurance does not so much transfer risk from the cedent, as it finances the cedent. During an event, the reinsurer makes funds available, expecting to be paid back later through higher subsequent premiums. In its pure form, the arrangement is just event-contingent borrowing. The absence of pure risk transfer contracts suggests that moral hazard and/or adverse selection are present.[32]

This "payback" interpretation of our evidence both is interesting and far-reaching. First, it suggests that there may be even less risk transfer than we thought. The numbers in Fig. 2, for example, are overstated, since they do not account for the present value of claim repayment. Second, the price and retention cycle we have seen subsequent to Hurricane Andrew are not evidence of explanations 1–3 or 4. Instead, they become evidence of a kind of "repayment cycle," whereby post-event periods are characterized by intensive repayment of recent event losses.

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[31] In some circumstances, higher prices may actually exacerbate the problem, making it impossible for the market to function. For a discussion of the implications of adverse selection on reinsurance contracts, see Cutler and Zeckhauser (1999).

[32] The contingent credit arranged for the Nationwide by J.P. Morgan has many of these features.

While it has a number of virtues in explaining the evidence, this explanation has two basic flaws. First, there is the question of time-consistency. What inhibits a cedent from switching reinsurers after making a claim? Since there is no contractual obligation to the original underwriter(s), the only way reinsurers could enforce repayment is through implicit collusion and barriers to entry into reinsurance. And, as we have already seen, market power by itself (even in the absence of moral hazard and adverse selection) helps explain the facts. It is also unlikely that new sources of capacity, represented by the Residential Re cat bonds, contain any such implicit "payback" concept.

Second, moral hazard and adverse selection seem relatively harmless for cat reinsurance as compared with other forms of insurance and reinsurance. Product liability protection, for example, can be understandably plagued with asymmetric information and moral hazard. Given the disclosure requirements, the large number of small risk units (i.e., houses, autos, etc.), and the presence of third-party modeling expertise for cat risk, it is hard to see how these distortions could be as important as in other areas. In the USAA and CEA transactions, for example, comprehensive disclosures to the third-party modeling companies who made their findings available to would-be investors limits the extent to which adverse selection is operative.

Finally, the high deductible and coinsurance in virtually all of these contracts reduces the scope for moral hazard and adverse selection. Once again, the evidence in Fig. 4 suggests that the pricing is most elevated at high layers where exceedence probabilities are low. Moral hazard and adverse selection problems would not predict this. Indeed, retentions and lower layers ought to be the most affected by moral hazard and adverse selection, so these effects imply that lower layers should be less efficient.

5.6. Explanation 6: *ex-post intervention by third-parties substitutes for insurance*

All of our previous explanations affected directly the supply of reinsurance. We were looking for factors that could cut supply, thereby increasing reinsurance prices and reducing reinsurance quantities. Here we begin to examine explanations that affect demand. Cuts in demand can explain low quantities, but only in association with low prices as well. So demand fluctuations alone are unlikely to be sufficient. Nevertheless there are likely to be a variety of factors at work on the demand side.

Ex-post financing of catastrophes occurs when other parties step in to transfer funds to those who experienced event losses. Chief among these entities is, of course, the US government. As is well known, the government has a major role in funding disasters at both state and federal levels, through a number of agencies, and through both the executive and legislative branches. Since the late 1970s, the Federal government has spent annually an average of $8 billion (current) dollars on disaster assistance. This is far greater than the average

annual loss born by reinsurers on US catastrophe coverage. In some forms of disasters, notably floods, the federal government has effectively eliminated the incentive for private insurance contracts. Indeed, before the Federal government stepped in to provide disaster relief, private insurers did offer flood insurance.[33]

The federal government is not the only entity involved in ex-post financing of catastrophes. State guarantee funds are often the next line of defense if an insurer is unable to meet its policy liabilities. And if the state fund is exhausted, then solvent insurance companies are often required to make up the difference. This creates two types of bad incentives. First, companies have an incentive to shift the burden onto the fund or other insurers before the fund is exhausted. Second, companies who do not act to shift high layer losses onto the pool are themselves likely to have to pay for others. Well-behaved insurers will wish to avoid doing business in states with guaranteed funds and pools. This strengthens the need for regulation and can create a kind of vicious cycle in market vs. regulatory incentives.

Ex post financing has a strongly negative effect on insurer's demand for reinsurance. It particularly reduces demand for the highest reinsurance layers, because third parties are more likely to intervene for larger events. However, it doesn't predict the behavior of USAA in its search to find new sources of higher layer capacity. Nor does it explain Berkshire Hathaway's attempt to block access by the capital markets to underwriting directly high-layer reinsurance. So ex post financing is at best a partial explanation for what we have seen thus far.

5.7. Explanation 7: agency issues distort insurance managers' decisions

We have already alluded to agency costs on the supply side as increasing the costs of reinsurer capital, and, therefore, the breakeven price of a contract from the supplier's perspective. Here we consider the impact of agency costs on an insurer's *demand* for purchasing reinsurance.

When agency considerations matter, managers act in ways that do not maximize firm value. They may, for example, maximize the value of their equity or options, rather than the value of the firm. The consequence is that value is transferred away from policyholders to shareholders and option holders.

This type of agency problem could be used to explain insurers' failure to purchase high layers of reinsurance.[34] Suppose, for example, that reinsurance is coinsured at a rate of 20% by the cedent (perhaps as a solution to moral hazard and adverse selection problems). In that case, a loss of five times surplus would eliminate the firm's surplus altogether through the coinsurance, forcing the firm into default. Marginal layers protecting against even higher marginal losses

[33] See Moss (1996).

[34] See Doherty and Smith (1993).

would not prevent default, and therefore provide no benefit to the firm or its managers. The policyholders would be the sole beneficiaries of such high-layer reinsurance. As a result, agency issues might suggest an upper limit on how large a loss cat reinsurance would cover.

Contrary to this is the notion that policyholders are willing to pay more for policies that are more likely to perform. Indeed, Merton (1997) argues that the firm's policyholders ("customers") are more risk averse with respect to firm credit risk than are the firm's capital providers. If true, then an insurer could purchase additional high-layer reinsurance and charge policyholders more than the present value of the benefits they receive, providing a gain to shareholders and management.[35]

These agency issues are probably not important for USAA. The firm follows conservative financial policies, holding very large levels of surplus in comparison with competitors. The beneficiaries of these conservative financial policies are policyholders, not shareholders. Because USAA is a mutual insurer, and therefore owned by its policyholders, USAA may provide a more reliable insurance product, yet offer lower returns on financial capital to these same people. This doesn't sound like the profile of a company in which agency problems encourage a transfer of value from policyholders. However, this also does not rule out the possibility that agency problems are helpful for explaining the paucity of high-layer reinsurance purchases in the aggregate data.

5.8. Explanation 8: behavioral factors dampen demand

A commonly cited reason for the low quantity of high-layer reinsurance is that the perceived likelihood that reinsurance will pay is too low to matter. For those who use expected utility-based or profit-maximization approaches, such as that in Section 2.1 above, insurance against severe, low-probability events is most valuable. But behavioralists have suggested that expected utility approaches fail to describe decision making.

One important failure is that people discount too heavily events they cannot readily perceive. For example, a famous study from the 1970s shows that the rate of smoking is higher among the general populace than among doctors (general practitioners), higher among general practitioners than among internists, and higher among internists than among specialists who work directly with lung cancer patients. Even when the consequences and probabilities of bad outcomes are well known, the consequences must be hammered home repeatedly in order to affect behavior.[36]

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[35] A related argument to the agency story is that the limited liability status of insurance capital providers leads to an upper limit on the reinsurance that a firm is willing to buy (see Huberman et al., 1983).

[36] See Tamerin and Resnik (1972) and Kunreuther et al. (1978).

A second behavioral effect is that individuals often seem "ambiguity" averse. A lack of clarity about the risks and events being insured may lead insurers and reinsurers to set premiums high.[37] Behaviorally, people seem to distinguish between risk (where probabilities are known) and uncertainty (where they are not). Uncertainty is inherently more ambiguous, and surveys suggest that individuals charge more to bear it.

Such behavioral factors can help explain some elements of the cat reinsurance buying patterns of USAA and CEA. The availability of objective, quantitative modeling of catastrophe losses starting in the mid-1990s could have created a greater appreciation of the benefits of hedging and prompted decision-makers to purchase higher coverage layers.

6. Conclusions

This paper has shown that the pattern of hedging against catastrophe event risk deviates from that predicted by theory, in the sense that protection against the largest events is often not purchased or is unavailable, and that prices deviate substantially from fair value. Our examination of clinical evidence yields a number of possible reasons for these departures from theory. We pursued these clues in eight different explanations for the clinical and large-sample facts' deviations from the theory.

What important lessons can we take from the evidence about catastrophe risk? After all, the cat market is small, with traded notional exposures in the (low) hundreds of billions, not the trillions as in major credit, mortgage pre-payment, and straight debt markets.

First, we clearly learn something about corporate risk management. Because managers of insurance companies purchase reinsurance at far above the fair price, they must believe that risk management adds considerable value. This statement is not easy to make in other markets, since it is so difficult to measure the value of corporate risk management, and since Modigliani Miller can accommodate any risk management policy when prices are fair. Of course, these conclusions follow from the assertion that fair prices can be more credibly measured for cat events than for other, less objectively-modeled exposures.

Second, the facts, especially the clinical data on Berkshire Hathaway and USAA, support the idea that there are capital market imperfections or barriers to capital entering into reinsurance. Cat bonds tend to lower these barriers, making the market more contestable. However, given the paucity of large cat events since the early 1990s, the subsequent decline in premiums and increase in

[37] See Kunreuther et al.(1993).

volumes are consistent both with an increase in contestability and a continuation of the standard cat event cycle. This view will be tested in the response to the next catastrophic event.

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